

# **The Effects of Oxygen on Junction Properties in CdS/CdTe Solar Cells**

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# The Effects of Oxygen on Junction Properties in CdS/CdTe Solar Cells

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## ABSTRACT

The effects of oxygen on junction properties in CdS/CdTe solar cells are investigated by a transmission electron microscopy (TEM) study of CdS/CdTe junctions grown by different techniques and in different environments. We find that the presence of oxygen in both CdS and CdTe films significantly suppresses the interdiffusion at the junctions. Without the presence of oxygen, the interdiffusion can be substantial. This results in fully consumed CdS regions, which have the same effects of pinholes, and high Te concentration  $\text{CdS}_{1-x}\text{Te}_x$  regions, which have much lower bandgap than CdS. This leads to reduced  $V_{oc}$  and  $J_{sc}$  for the CdS/CdTe solar cell. Oxygen impurity in chemical-bath deposited (CBD) CdS films is therefore proposed to be the main cause for the different solar cell performance using CBD-CdS and non-CBD-CdS as window layers.

## 1. Introduction

So far, most high-efficiency CdS/CdTe solar cells utilize CdS layers grown by CBD [1-3], with the sole exception of ref. [4]. This wet growth process is, however, problematic in commercial manufacturing. An all-dry CdS growth step like close spaced sublimation (CSS) is manufacturally more favored, but usually yields lower efficiency. It is known that CBD CdS films contain a high concentration of impurities, mainly oxygen, and usually have lower crystal quality than CSS CdS. The fact that the better-quality CdS films could not lead to better CdS/CdTe solar cells has long been puzzling. Incorporation of oxygen in non-CBD CdS films has been found to achieve better efficiency. It is therefore reasonable to assume that it is oxygen impurities in CBD CdS films that are responsible for the better cell performance. However, so far there are no systematic investigations to support this assumption.

In this paper we provide systematic TEM studies of CdS/CdTe junctions to elucidate why and how oxygen present in CdS and CdTe films affects the cell performance. We find that oxygen affects the cell performance by controlling the interdiffusion at the junctions. Without the presence of oxygen, the interdiffusion can be substantial, resulting in fully consumed CdS regions, which have the

same effects as pinholes, and high Te concentration  $\text{CdS}_{1-x}\text{Te}_x$  regions, which have much lower bandgap than CdS. This leads to reduced  $V_{oc}$  and  $J_{sc}$  for the CdS/CdTe solar cell. Oxygen impurity in CBD-CdS films is therefore proposed to be the main cause for the different solar cell performance using CBD-CdS and non-CBD-CdS as window layers.

## 2. Experimental

All CdS/CdTe junctions were grown on  $\text{SnO}_2$ -coated silicon substrates under conditions identical to those used in fabricating high efficiency devices. In order to understand the effects of oxygen in CdS films and CdTe films separately, we designed two sets of samples: 1) CdTe films grown on CBD CdS, as-grown CSS CdS, and CSS CdS annealed in oxygen. The CdTe films were grown by CSS without the presence of oxygen during the growth. 2) CdTe films were grown on as-grown CSS CdS films. The CdTe films were grown with and without the presence of oxygen.

## 3. Results

Figs. 1 (a) and (b) show cross-sectional TEM images of an as-grown CSS CdS/CdTe and an oxygen-annealed CSS CdS/CdTe device after vapor  $\text{CdCl}_2$  treatment, respectively. Fig. 1 (c) is a cross-section of the CBD CdS/CdTe device structure. The Si,  $\text{SnO}_2$ , and CdTe layers can be clearly identified in all images. In Fig. 1 (a), the CdS layer is not visible in some regions, as indicated by the arrow A. The CdTe seems to contact the  $\text{SnO}_2$  layer directly, indicating total consumption of the CdS. In other areas, indicated by arrow B, the CdS layer is seen but with significantly decreased thickness suggesting that consumption is spatially variable in the plane of the film. Interdiffusion in the oxygen-annealed CSS CdS sample, Fig. 1 (b), contrasts this behavior sharply. The CdS layer in this case is still very visible. This strongly indicates that oxygen present in CdS layers significantly suppresses the interdiffusion. Without the presence of oxygen, substantial interdiffusion can take place and can subsequently lead to fully consumed CdS regions, which have the same effects as pinholes, and high Te concentration  $\text{CdS}_{1-x}\text{Te}_x$  regions, which have much lower

bandgap than CdS. This leads to a reduced  $V_{oc}$  and  $J_{sc}$  for the CdS/CdTe solar cell.

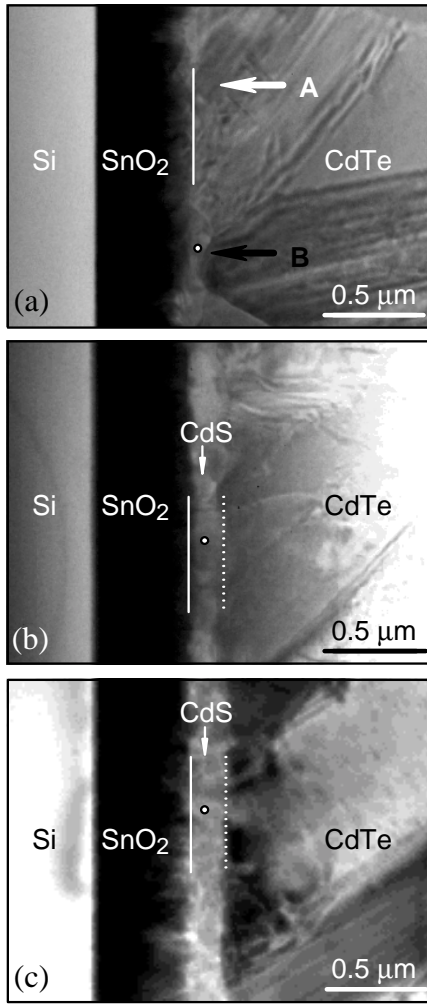


Fig. 1. Cross-sectional TEM images of CdS/CdTe interface using (a) as-grown CSS CdS layers, (b) CSS CdS layers annealed in oxygen, and (c) CBD CdS layers.

To demonstrate the  $J_{sc}$  loss due to the formation of high Te concentration  $CdS_{1-x}Te_x$  regions, we calculated the current losses in CdS/CdTe devices with different thickness of CdS layer consumed to form  $CdS_{1-x}Te_x$ . Zero collection is assumed in the CdS layers. Calculated external QE curves are shown in Fig. 2. It is seen that for a given CdS film thickness, Te alloying decreases QE due to the reduced bandgap of the  $CdS_{1-x}Te_x$  alloy. For the 100-nm thick CdS case, the integrated device current decreased from 22.02 mA/cm<sup>2</sup> to 18.32 mA/cm<sup>2</sup> as Te alloying increased from 0 at.% to 20 at.%. For the thinner CdS film, the drop in current was not as pronounced: 22.55 mA/cm<sup>2</sup> to 20.44 mA/cm<sup>2</sup>. Te alloying causes a large drop in the CdS bandgap which reduces the quality as an optical window.

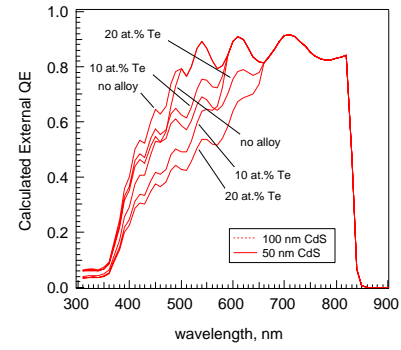


Fig. 2. Calculated external QE curves for CdS/CdTe devices for various amounts of Te alloying in the CdS layer.

In the CdTe side, we find that oxygen suppresses S diffusion, especially along the grain boundaries. Our observations clearly suggest that the S diffusion in the CdTe side follow the scenario shown in Fig. 3. Grain boundaries significantly assist S diffusion in the CdTe layer when the CdTe is grown without the presence of oxygen. However, grain boundaries do not enhance the S diffusion in CdTe when it is grown in the presence of oxygen. The reason is likely to be the formation of Cd-O bonds at the grain boundaries, which are resistant to the S diffusion.

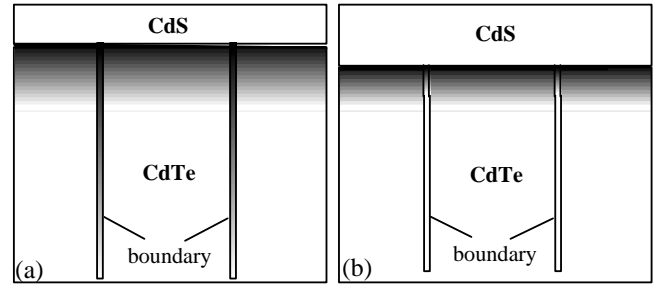


Fig. 3. Models for the S profiles inside grains and along grain boundaries for the CdTe grown (a) without and (b) with the presence of O during growth.

#### 4. References

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